Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 1 Wire Chamber

AUTHOR: Tom O'Connor – Argonne National Laboratory

DATE: October 21, 2011

REVIEWER(S): Kevin Bailey – Argonne National Laboratory

ABSTRACT: This document describes an aluminum framework designed to secure and install a wire chamber in E906.

DESIGN:

The wire chambers for Station 1 were originally built for E866. These chambers weigh approximately 100 pounds (see Figure 1). In order to use them in E906 steel adapter plates will be mounted to the two upper endplates of the wire chambers. The adapter plate is shown in Figure 2. The four slots on the adapter plate are identical to the bottom four slots on the endplate and the adapter will be placed on top of the endplate with these slots aligned such that both plates can be mounted to the chamber framework with ¼-20 screws. Aluminum extrusions will be fastened to the adapter plates on one end. The other end of the extrusions will be attached to an aluminum I-beam (WF4 x 4.76) which will be used to hang the detector in the E906 beamline. The final assembly is shown in Figure 3. The length of the extrusions is designed to place the center of the wire chamber at the beam axis. The extrusions and fasteners, produced by 8020 Inc., are shown in Figure 4.

During assembly, the chambers, 8020 extrusions, and I-beam will be laid out horizontally. After assembly the entire package shown in Figure 3 will be lifted and rotated to be installed vertically into the E906 beamline. The following table lists the mechanical properties of the extrusion profiles relevant to this report.

Part No.	Cross Section	Area (in^2)	Material	lbs/foot	Ix (in^4)	Iy (in^4)
1030	1" x 3"	1.1596	6105-T5*	1.3498	0.9711	0.1238

- UTS = 38ksi minimum, Yield = 35ksi minimum, Emod = 10.2e6 psi,
- Allowable Tensile Stress = 19.5ksi*

*(per Aluminum Design Manual Part IA, 1994).

Table 1 – Mechanical Properties of 8020 Extrusions in Station 1 Wire Chamber Assembly per 8020 Fractional Parts Catalog – 16th edition

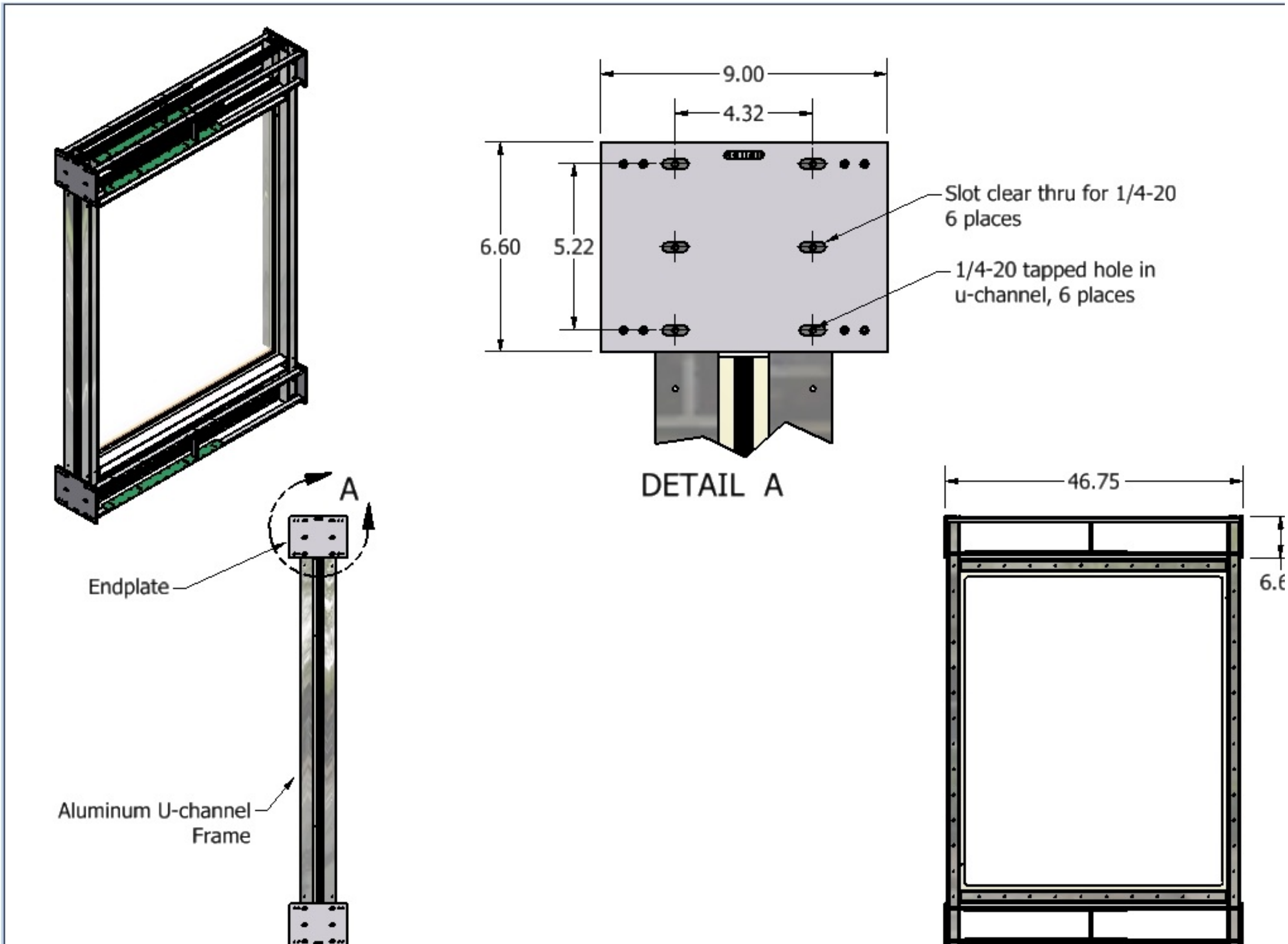
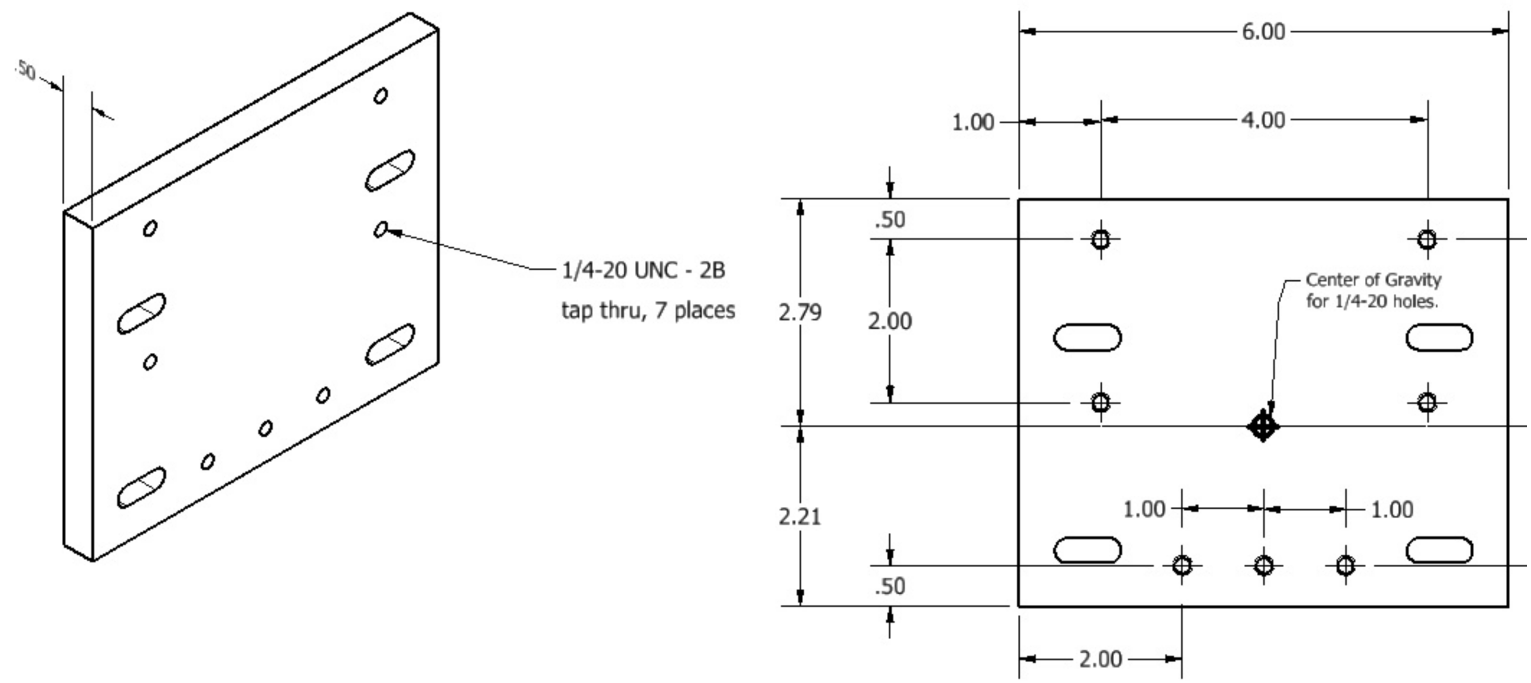


Figure 1 - Station 1 Wire Chamber from E866



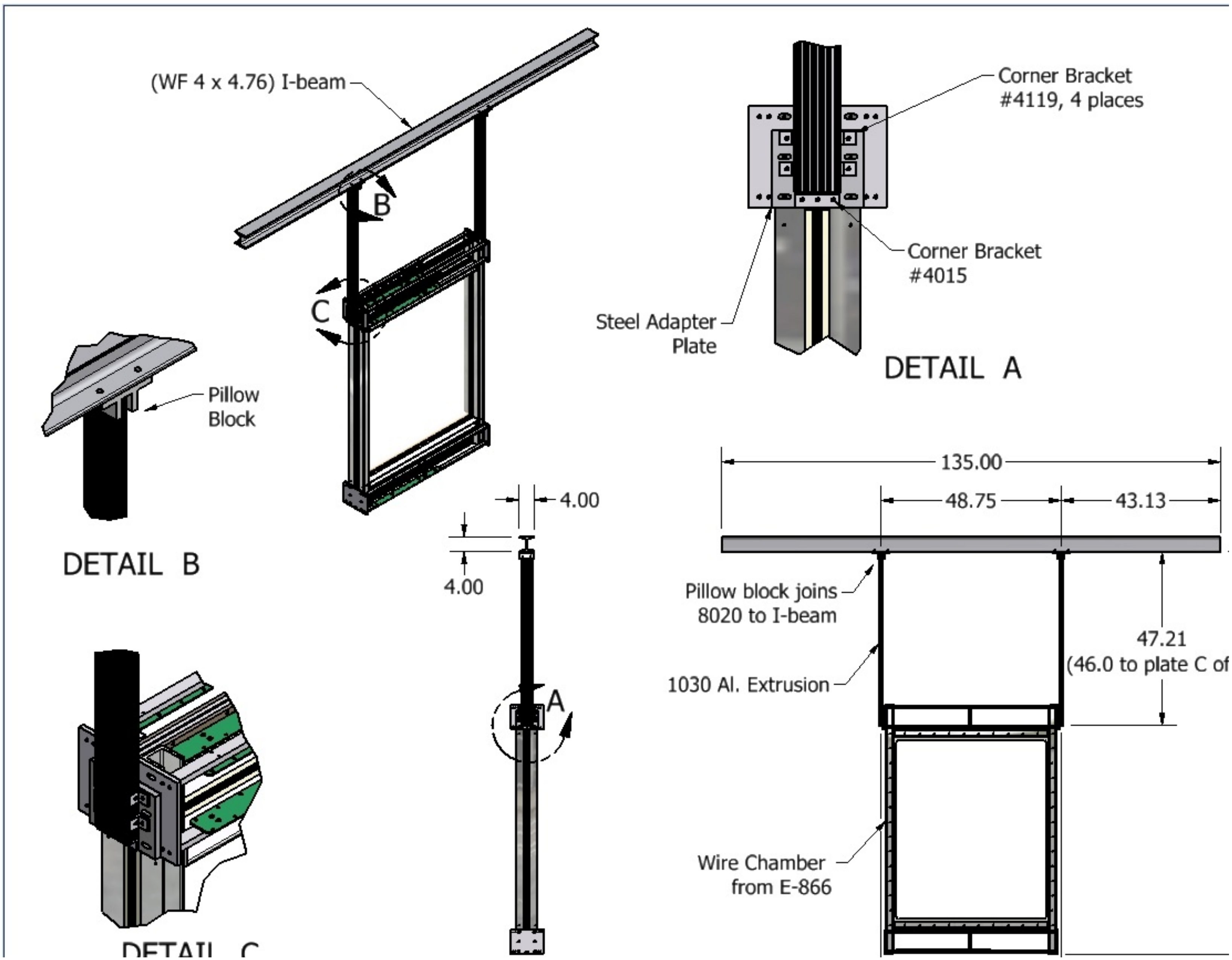
NOTES:

1. Plate is attached by placing it on top of detector endplate, aligning slots with the 4 bottom slots of the endplate, and fastening to the aluminum u-channel with 1/4-20 screws.

2. 8020 corner brackets are attached to this adapter plate via the seven (7) 1/4-20 tapped holes.

3. The "Center of Gravity" applies to the 1/4-20 tapped holes and is the point at which the resisting moment is calculated.

Figure 2 - Adapter Plate for Station 1, Steel


(WF 4 x 4.76) I-beam
B
C
Pillow
Block
DETAIL B
4.00
4.00
A
DETAIL C
Corner Bracket
#4119, 4 places
Corner Bracket
#4015
Steel Adapter
Plate
DETAIL A
135.00
48.75
43.13
Pillow block joins
8020 to I-beam
47.21
(46.0 to plate C of
1030 Al. Extrusion
Wire Chamber
from E-866

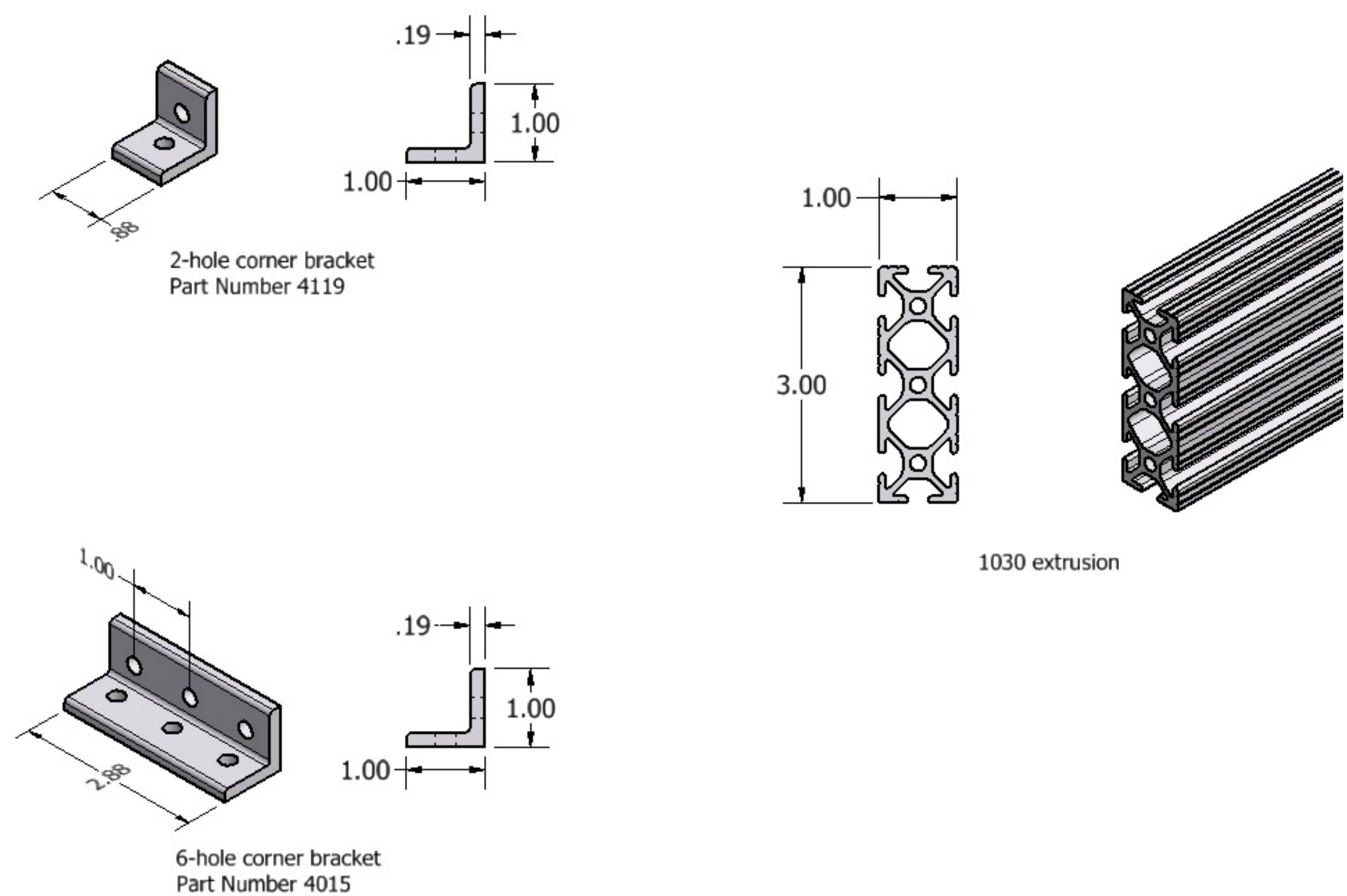


Figure 4: 8020 components used in Station 1 Wire Chamber
(all holes/slots clear for 1/4-20)

ANALYSIS:
The detector assembly will be built horizontally and then lifted/rotated and installed vertically in the E906 beamline line by resting the ends of the bottom surface of the aluminum I-beam onto the top surface of a pair of cantilevered steel I-beams that have been welded onto the top of FMAG. This will be done by wrapping slings around the I-beam and using the crane in NM4. The assembly must be strong enough to withstand the rotation from horizontal to vertical and also be strong enough to hang vertically for the duration of the experiment. Each of these cases is treated separately as follows:

Lifting/Rotating:
When the detector is horizontal it can be lifted at one edge (by the I-beam) and re-oriented to the vertical. If treated as cantilevered beams subject to concentrated loads at the free end, then the resulting stress and deflection of the 1030 extrusions can be calculated using standard formulas:

Stress at the free end of the beam: $$s = \frac{-WL}{Z}; \qquad \textbf{(1)}$$

Deflection at free end: $$y = \frac{WL^3}{3EI}; \qquad \textbf{(2)}$$

Where:
- W is the weight applied at the mounting point (50lb)
- L is the length of the extrusion (47.21 inches)
- I is the moment of inertia, 0.9711in^4
- Z is the section modulus (I/1.5in = 0.6474in^3)
- E is the modulus of elasticity

Substituting the values into equation (1) yields:

$$s = -\frac{50lb \times 47.21in}{0.6474in^3} - 3646lb/in^2$$

Likewise, substituting the values into equation (2) yields:

$$y = \frac{50lb \times (47.21in)^3}{3 \times 10.2e6\,psi \times 0.9711in^4} = 0.53in$$

The Allowable Bending Stress for a 1030 extrusion with a length of 47.21" (per Aluminum Design Manual Part IA, 1994) is 21.21ksi. The maximum stress of 3646psi, when compared to this value for Allowable Bending Stress, provides a safety factor of 21210/3646 = 5.8. The maximum deflection of 0.53" occurs at the start of the rotation and will fall to zero as the array is made vertical.

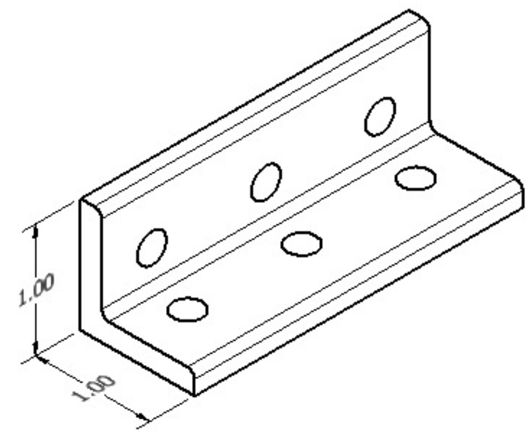
The bottom end of the 1030 extrusion is attached to the steel adapter plate using four of the 4119 corner brackets and one 4015 corner bracket and ¼-20 screws. See Figure 3, Detail A and Detail C. A total of 7 ¼-20 screws will be used to secure each extrusion to the adapter plate. The center of gravity of this screw pattern is shown in Figure 2. This point lies a distance of 46.0" from the top end of the 1030 extrusion, as shown in Figure 3. At the start of rotation a resistance moment is generated about this center of gravity. The magnitude of this moment is 50lb x 46" = 2300 lb-in. This moment can be expressed as a resisting couple acting on separate groups of four screws above the center of gravity and three screws below the center of gravity. The distance for this couple is 3" and the load on each group of screws is 2300lb-in/3in = 767lb. The worst case load is applied to the group of three screws and is (767-lb + $^{50}/_{7}$-lb)/3 = 258-lb per screw. With a minor diameter of 0.1887" and an area of 0.028-in^2, the resulting initial shear in each of these screws is 1367psi. The allowable shear, per the Manual of Steel Construction 9th edition, is 17ksi which is far in excess of these expected actual values.

The holes in the 6-hole corner bracket (part # 4015) are also subject to a tear out stress as a result of the resisting moment. This worst case magnitude of this tear out stress is 2190psi, as calculated in Figure 5. The bracket has yield strength of 35ksi. Assuming shear strength is 40% of yield strength results in an allowable shear of 14ksi which is also far in excess of the expected actual value. In addition to the tear out stress, the bracket also experiences a shear stress equal to the load divided by the cross sectional area. The worst case magnitude of this stress (see Figure 5) is 918psi and is acceptable when compared to the allowable of 14ksi. It is worthwhile to note that these values for tear out and shear are largest at the start of rotation due to the resistance moment and will fall significantly as the detector is made vertical.

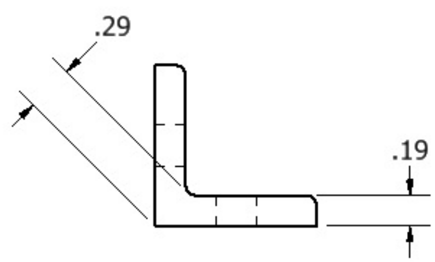
The adapter plate in turn is attached to the detector frame at each slot using ¼-20 screws. Each of these screws is subject to a shear of 12.5-lbs (4 screws with a total load of 50-lbs) and the resulting shear stress is 446psi which is acceptable. All of the 8020 corner brackets will be secured to the 8020 extrusion with an applied torque between 4ft-lb and 6ft-lb per the torque specification described in the 8020 Fractional Parts Catalogue – 16th Edition, p. 59.

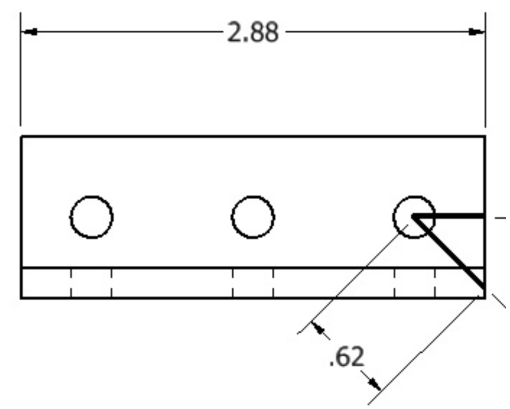
Two aluminum pillow blocks are used to attach the top end of the 1030 extrusions to an aluminum I-beam (WF4 x 4.76). Each pillow block is attached to the extrusion using three screws with ¼-20 threads. They are also attached to the I-beam using four 3/8-16 bolts. At the start of rotation each ¼-20 screw (6 screws total) will experience a shear of roughly 16.7-lbs which will vanish as the array is rotated. With a minor diameter of 0.1887 and an area of 0.0280in^2, the resulting shear stress in each ¼-20 screw is 595psi. Likewise, at the start of rotation each 3/8-16 bolt (8 bolts total) will experience a shear of roughly 12.5-lbs which will vanish as the array is rotated. With a minor diameter of 0.2970 and an area of 0.069-in^2, the resulting shear stress in each 3/8-16 screw is roughly 181psi. These are acceptable stresses for Grade 5 screws.

Hole Tearout Analysis:
Load on hole = 258 pounds
Effective Cross Sectional Area:
A = 2(0.62)(0.19)
= 0.1178-in^2
Stress on hole = 258/0.1178 = 2190psi



Shear Analysis:
Load on bracket = 767 pounds
Shear Area:
A = (0.29)(2.88)
= .8352-in^2
Shear on bracket = 767/0.8352 = 918psi





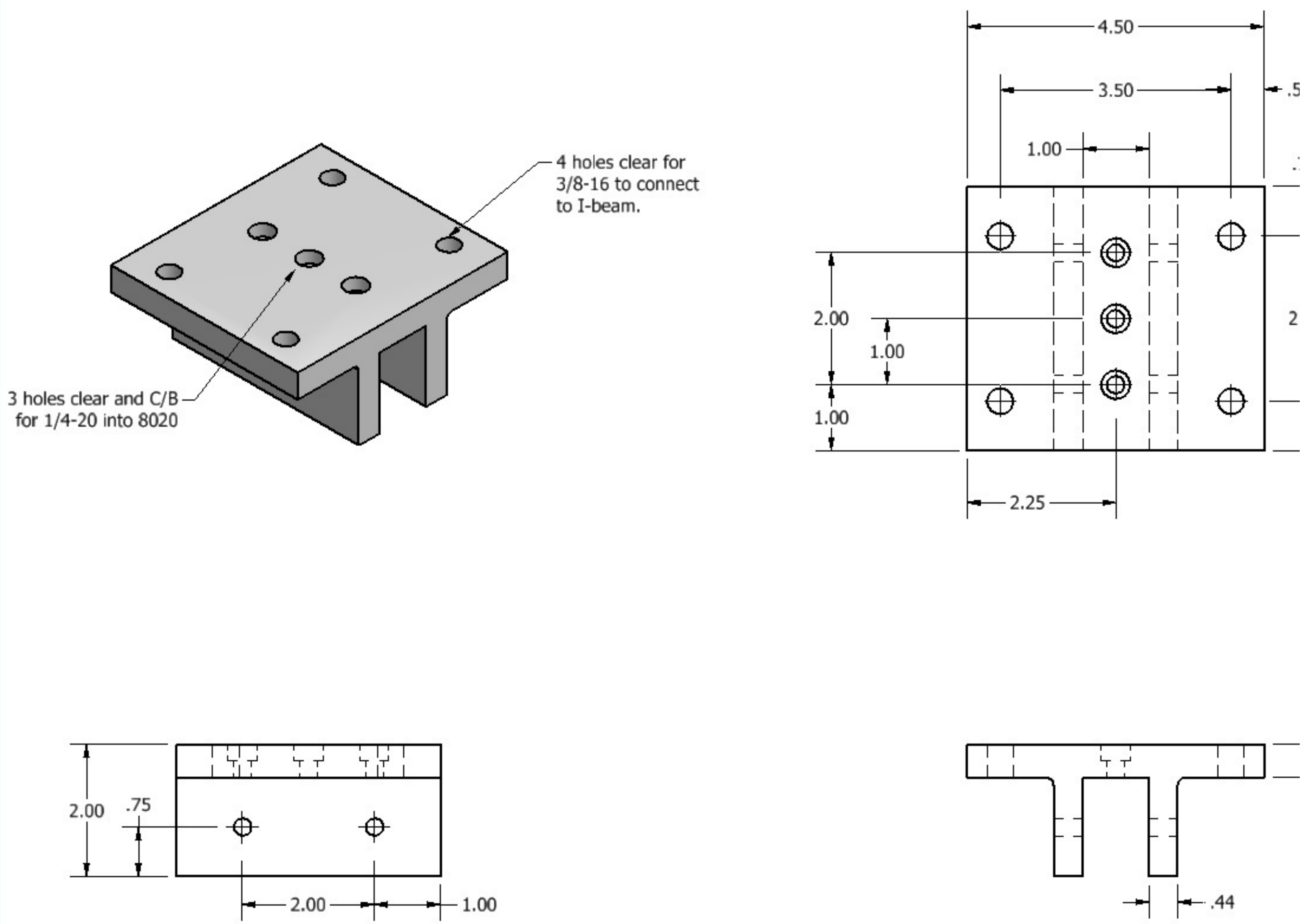


Figure 6: Aluminum Pillow Block for

Placement in E906 Beamline:
Once the detector assembly is vertical the weight of the chambers is borne by two 1030 extrusion that run vertically from the I-beam to the adapter plates. With an area of 1.1596in^2 (Table 1) and a weight per column of 50-lbs, the tensile stress on each vertical extrusion is 50/1.1596 = 43psi and is not a cause for concern when compared to the allowable tensile stress of 19.5ksi.

This detector assembly will be inserted into the beam line by resting the ends of the bottom surface of the aluminum I-beam onto the top surface of a pair of cantilevered steel I-beams that have been welded onto the top of a nearby magnet and perpendicular to the plane of the array. Once in place this aluminum I-beam will experience stress and deflection from the weight of the detector. If treated as a beam supported on both ends subject to concentrated identical loads equidistant from center then the stress and deflection of the I-beam can be calculated using standard formulas:

Stress at center of constant cross section: $$s = \frac{-Wa}{Z} \qquad \textbf{(3)}$$

Maximum deflection at center: $$y = \frac{Wa}{24EI}(3L^2 - 4a^2) \qquad \textbf{(4)}$$

Where:
- W is the weight of each load (50lb)
- L is the length of the beam(135 inches)
- a is the distance from the end to the load (43.13 inches)
- I is the moment of inertia of WF4 x 4.76 beam (10.8in^4)
- Z is the section modulus
- E is the modulus of elasticity

Substituting the values from Table 1 into equation (3) yields:

$$s = -\frac{50lb \times 43.13in}{\left(10.8in^4 \middle/ 2in\right)} = -399.4lb/in^2$$

Likewise, substituting the values into equation (4) yields:

$$y = \frac{1}{24}\left[\frac{50lb \times (43.13in)}{10.2e6psi \times 10.8in^4}\right]\left[3(135in)^2 - 4(43.13in)^2\right] = 0.039in$$

The bending stress of 399.4psi and deflection of 0.039in of the WF4 x 4.76 I-beam are not a cause for concern.

Finally, while in the beam line the weight of the entire array/framework assembly is held by the six ¼-20 screws and eight 3/8-16 bolts in tension. Each ¼-20 screw experiences a tensile force of roughly 16.7-lbs. With a tensile stress area of 0.0318in^2, the resulting tensile stress in each ¼-20 screw is 524psi. Likewise, each 3/8-16 bolt experiences a tensile force of roughly 12.5-lbs. With a tensile stress area of 0.0774in^2, the resulting tensile stress in each 3/8-16 screw is 161psi. These are acceptable stresses for Grade 5 screws.